

Innovation for Our Energy Future

Solar Resource Assessment Methodologies

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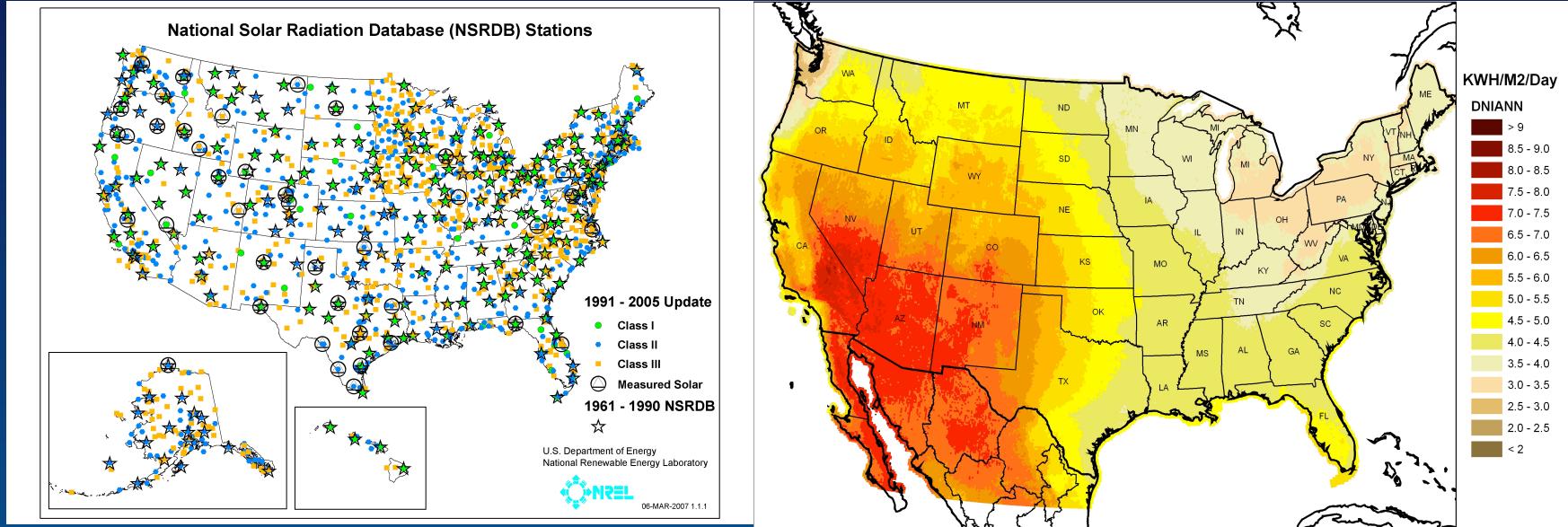
Presented at the Western Wind and Solar Integration Study
Stakeholders Meeting
August 14, 2008
Embassy Suites Hotel, Denver, CO



Solar Resource Assessment Status

- Updated U.S. National Solar Radiation Data Base (NSRDB)
 - Modeled estimates of hourly solar resources derived from cloud cover observations at 1454 fixed surface locations for the period 1991-2005; estimated accuracy of ±10-20%. Mapped by location.
 - Satellite-derived estimates of hourly solar resources produced by SUNYA and NREL at 10 km spatial resolution for 1998-2005; estimated accuracy of ±10-20%. Includes monthly and annual average resources as well as time-series information from individual grid cells; can be mapped.
- Worldwide satellite-derived solar radiation data available from NASA: coarse spatial scale (~1° latitude/longitude grid cells). Monthly global, direct, and diffuse values averaged over the collection period July 1983 to June 2003
- IEA/SHC Task 36 to benchmark international solar resource assessments and resource forecasting methodologies developed by institutions around the world
- High-quality historical measurements available at a few dozen stations around the U.S., including NREL. Current number of sites under federal support is far fewer than in previous decades and declining.

NSRDB Update – 1991-2005

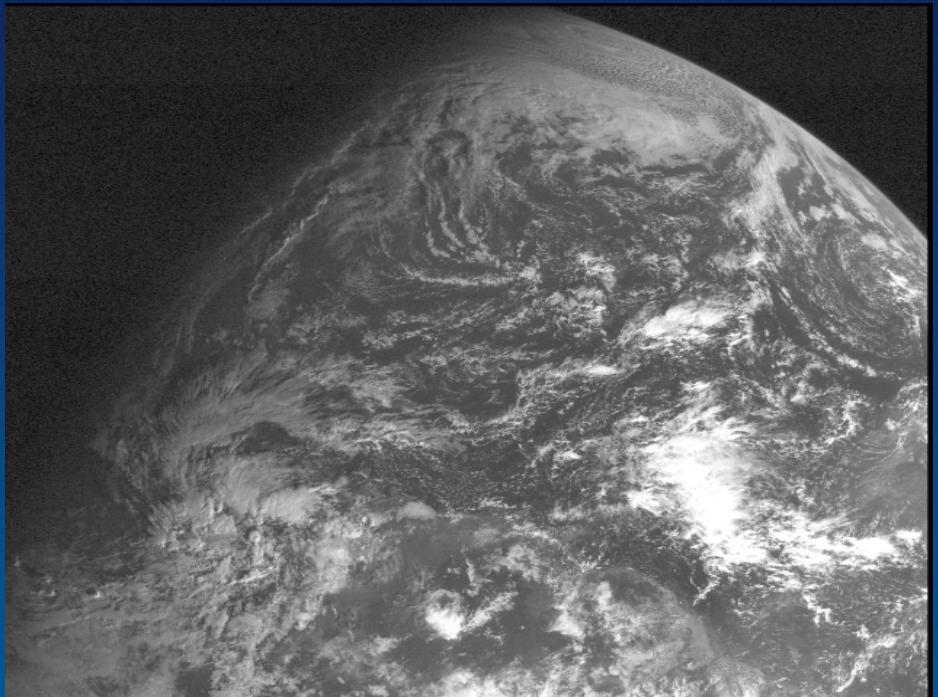


- **NSRDB Station Data**
- Contains hourly solar and meteorological data for 1454 ground locations, 1991-2005
- Distributed by National Climatic Data Center and NREL via web

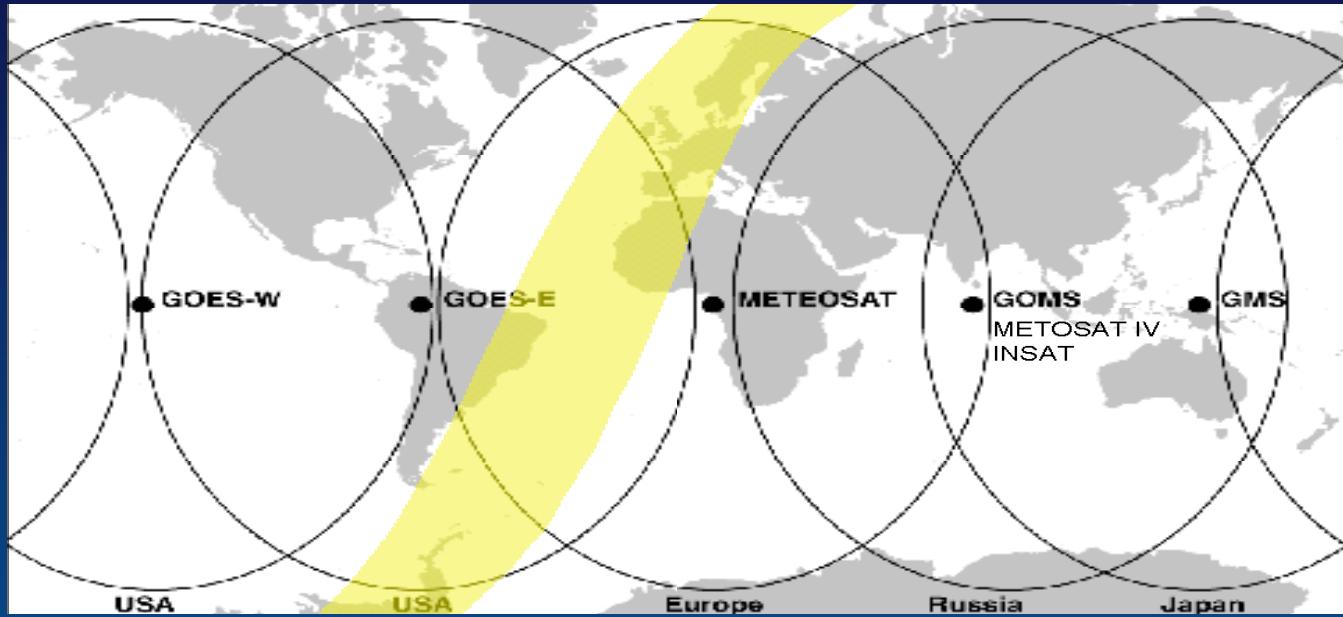
- **NSRDB Gridded SUNY Data**
- Includes hourly satellite modeled solar data for years 1998-2005 on 10km grid
- Hourly solar for any location can be combined with hourly met data for PV and CSP simulation.

Satellite Imagery

- Provides cost-effective means for solar resource estimates over large areas with much improved spatial resolution
- Two approaches
 - Convert satellite imagery to solar estimates (Perez)
 - Use satellite-derived cloud cover information (NREL/CSR, or NASA/SSE)



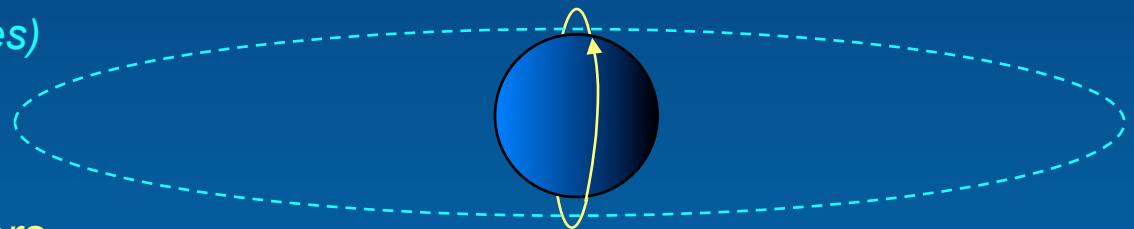
Source: Richard Perez



Geostationary Weather Satellites

- *High resolution*
(decaying at high latitudes)

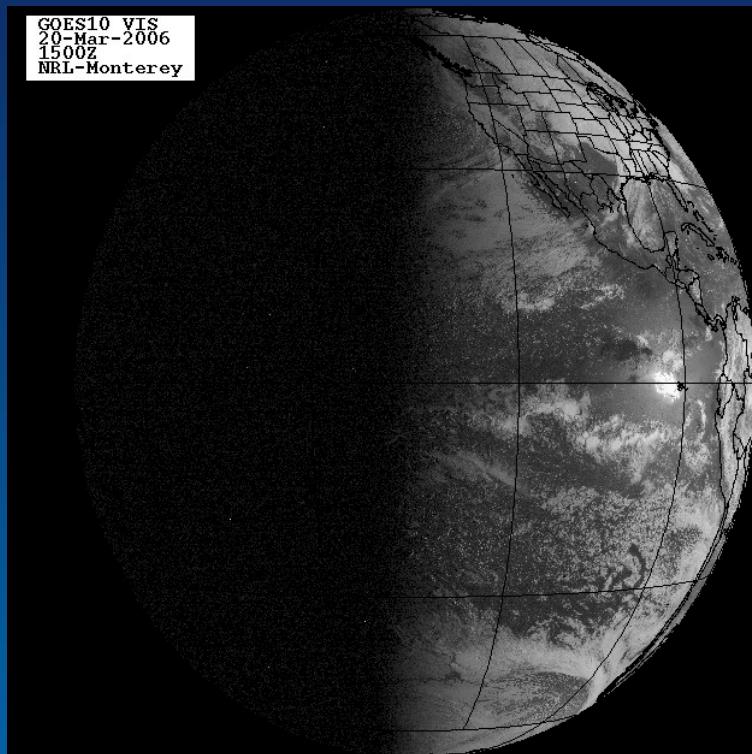
- *Continuous in time*



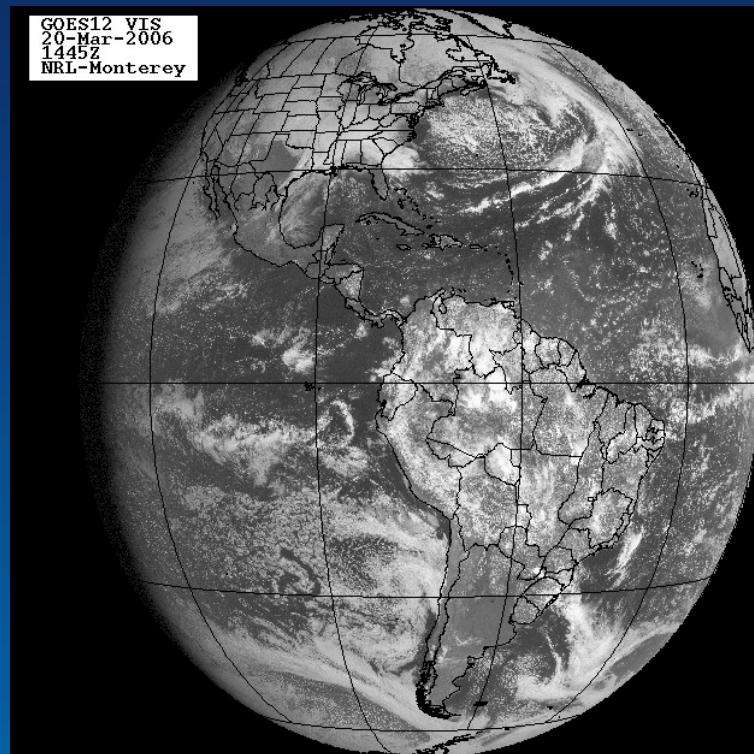
Polar Orbiters

- *Very High resolution
at all latitudes*
- *Twice a day only*

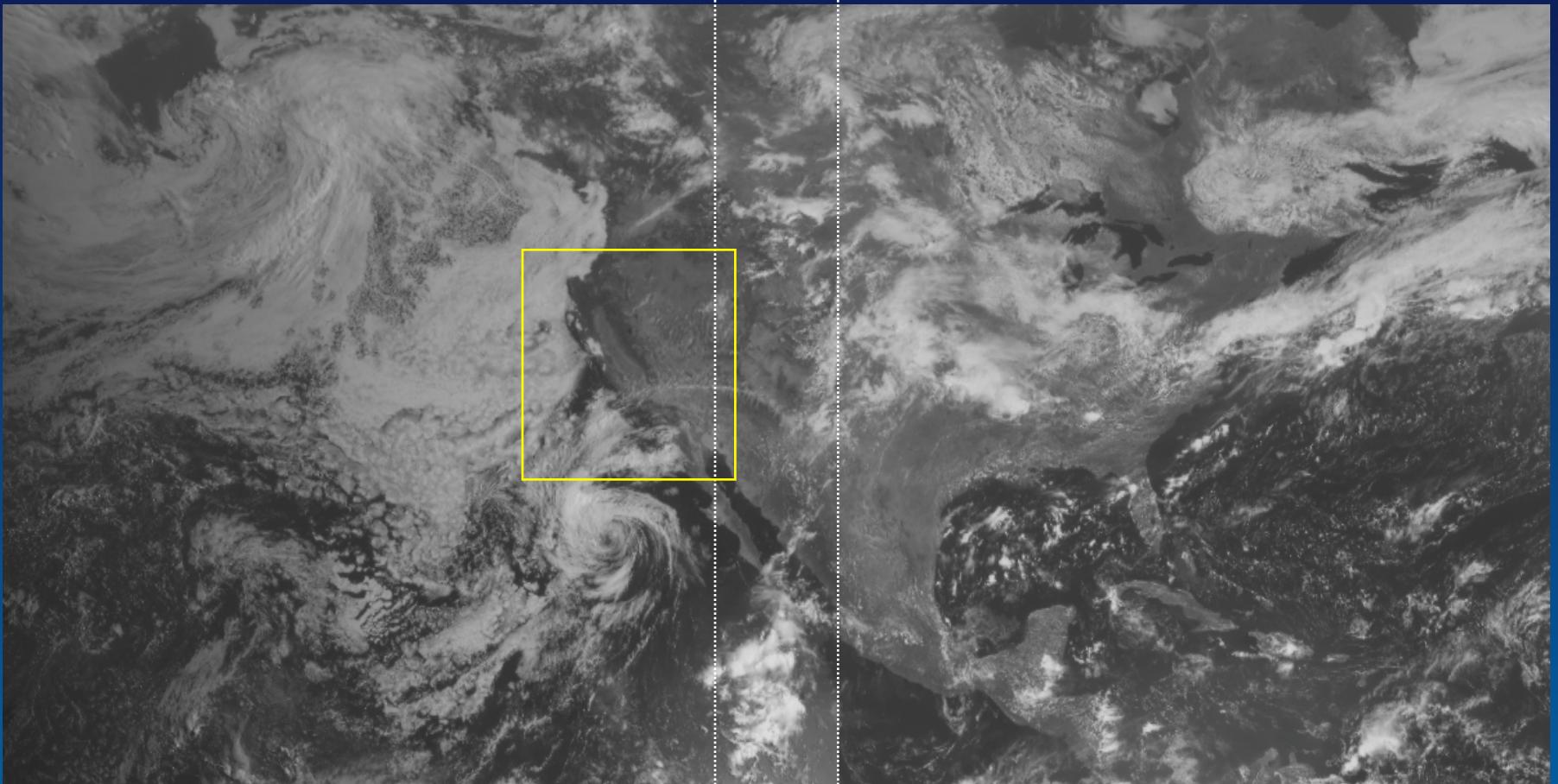
High-Res (10-km) Method of Dr. Richard Perez State University of New York, Albany



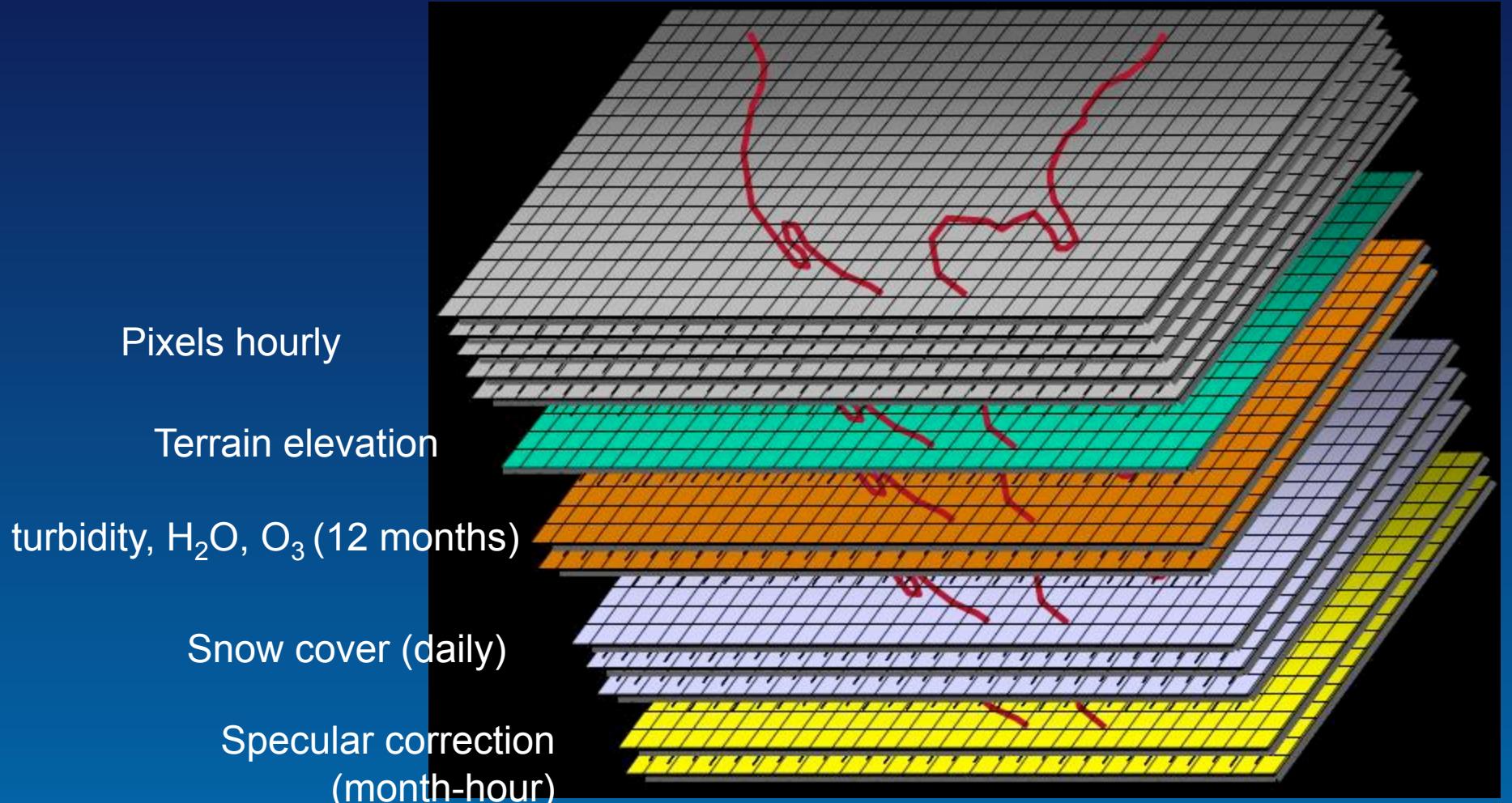
GOES-9/10

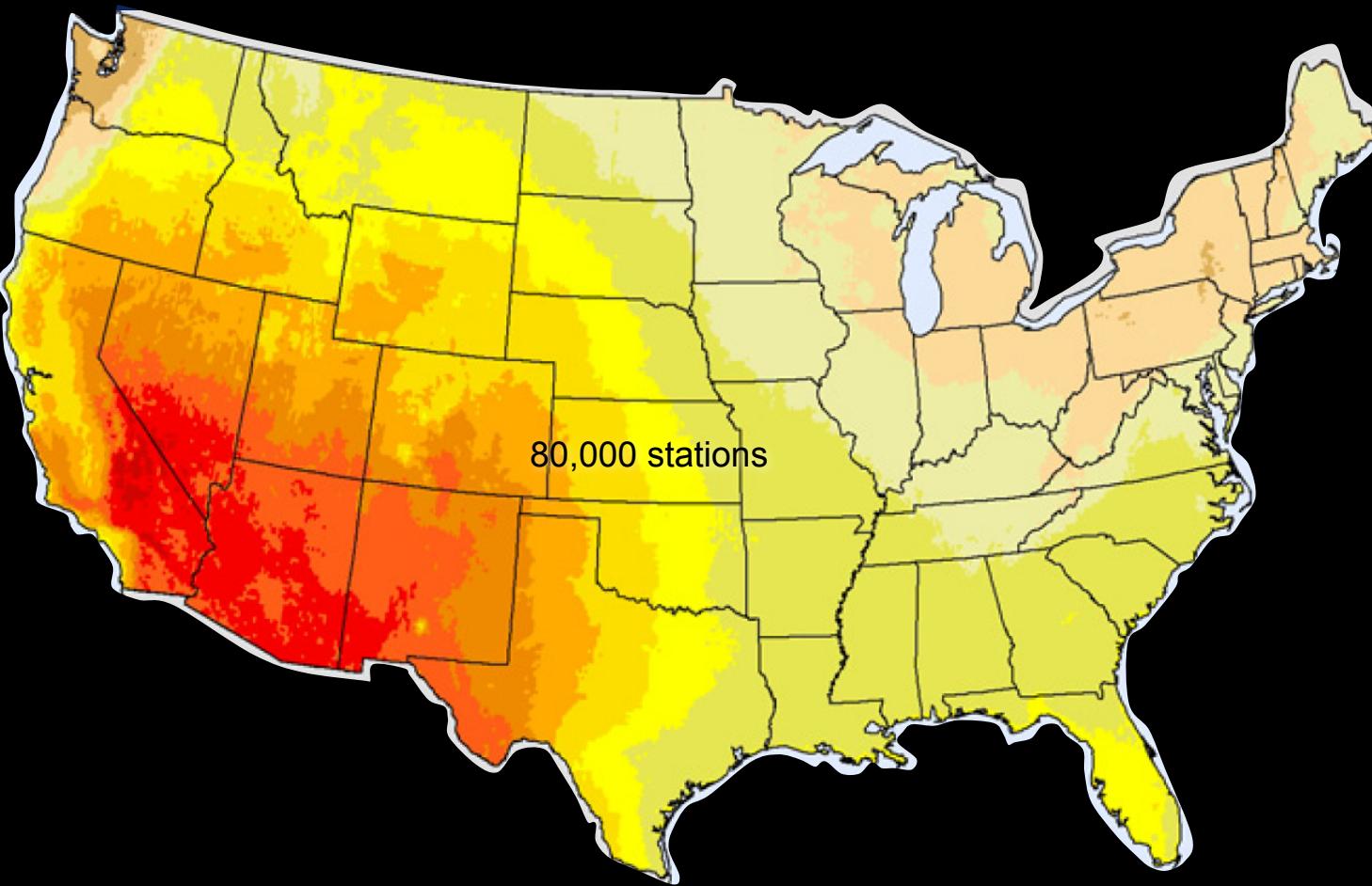


GOES-8/12



Operational Model

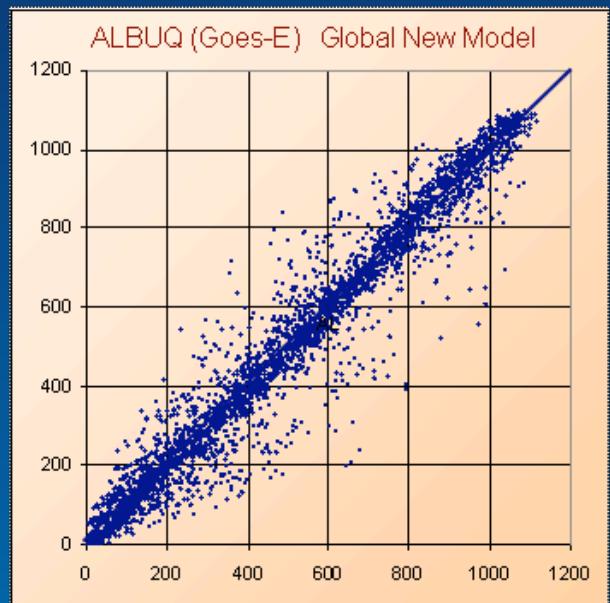
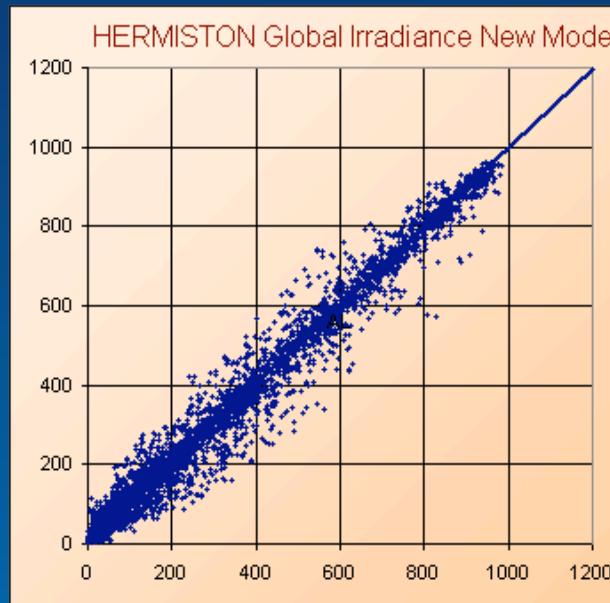
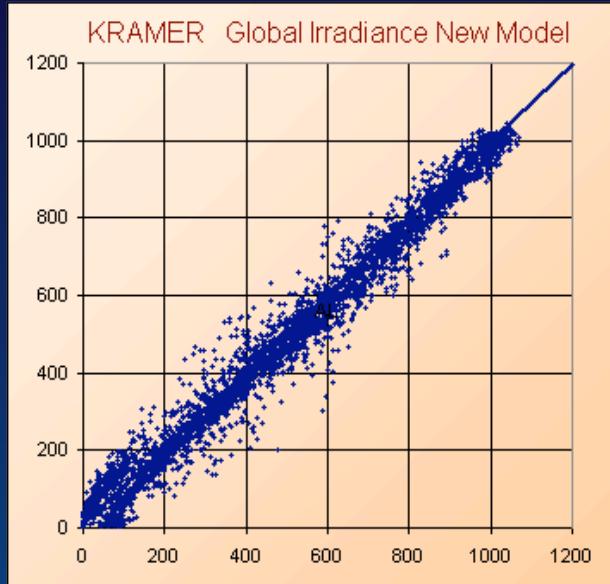
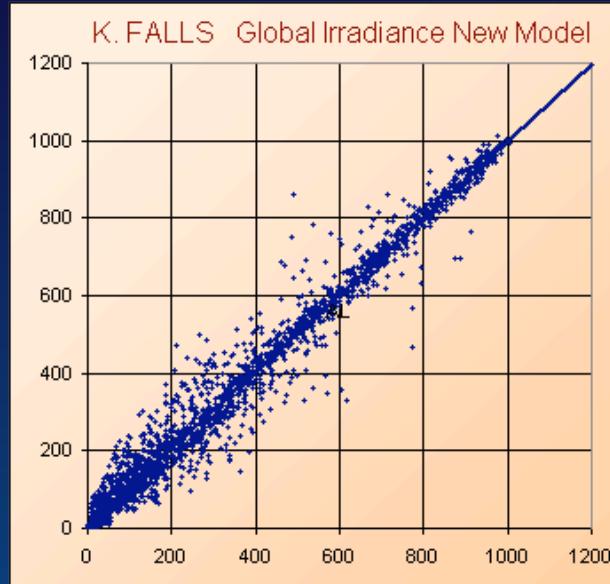




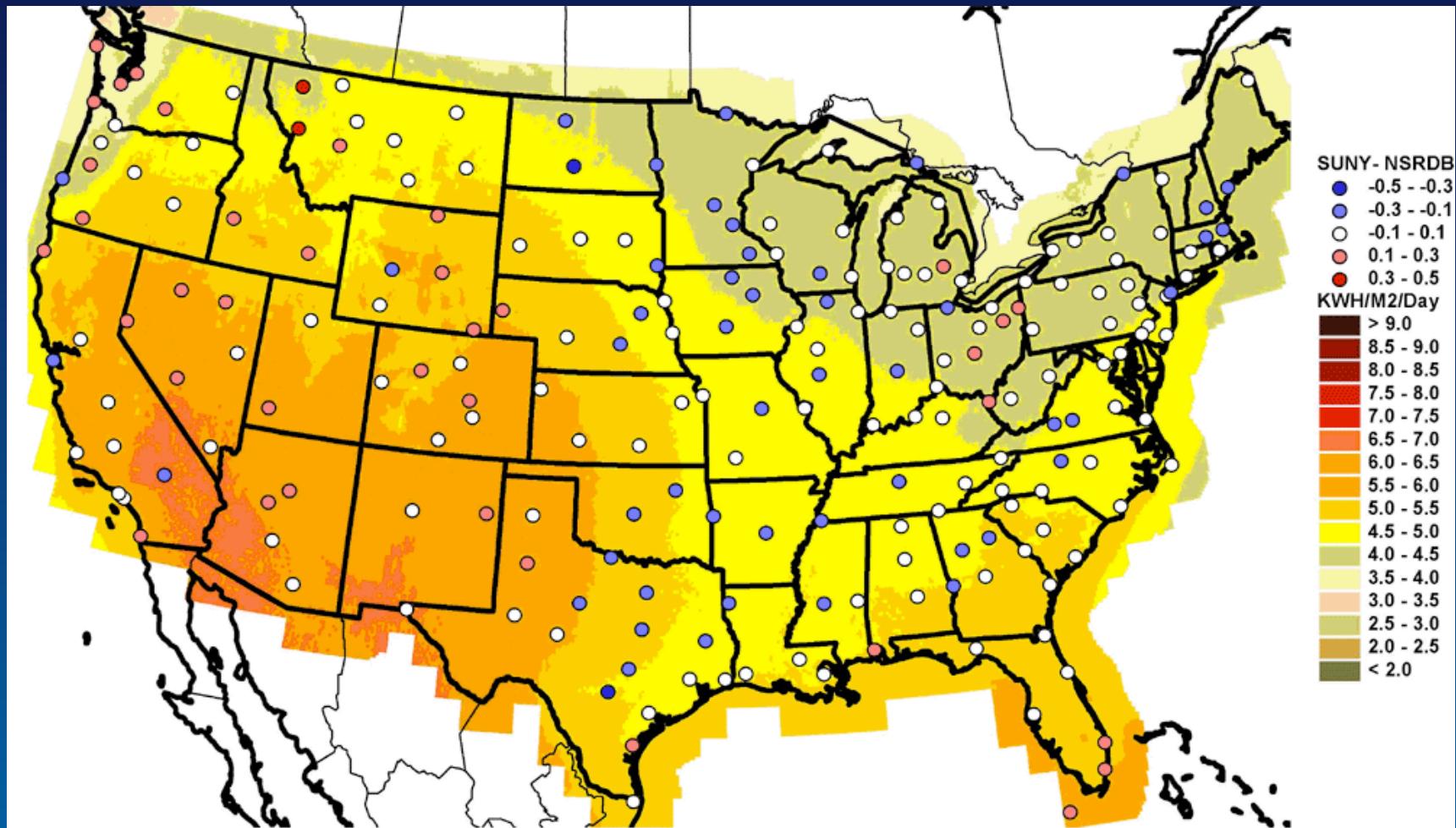


Ground Truth Sites

Richard Perez, et al.

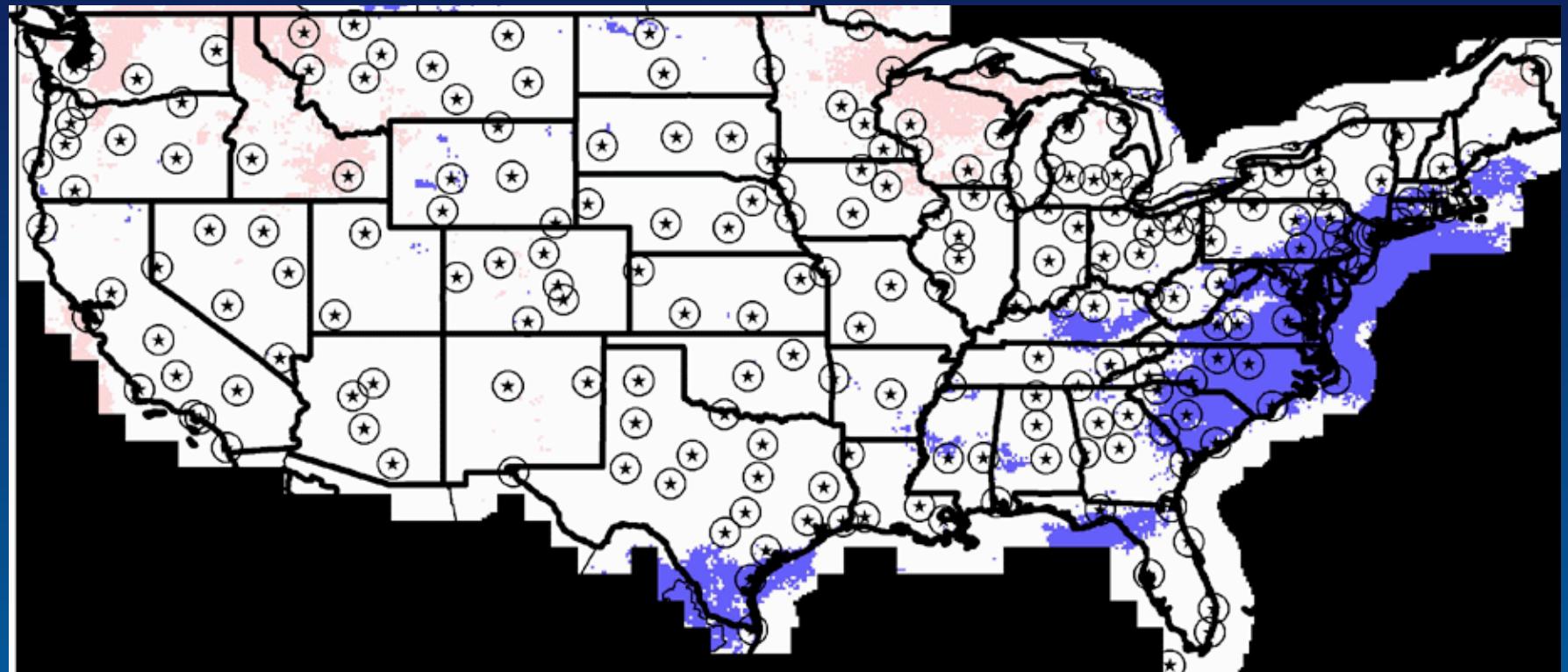


8-year NSRDB/SUNY Mean Data



Global radiation on latitude tilt, for NSRDB/SUNY data
1998-2005. Circles show SUNY minus 1961-1990 NSRDB

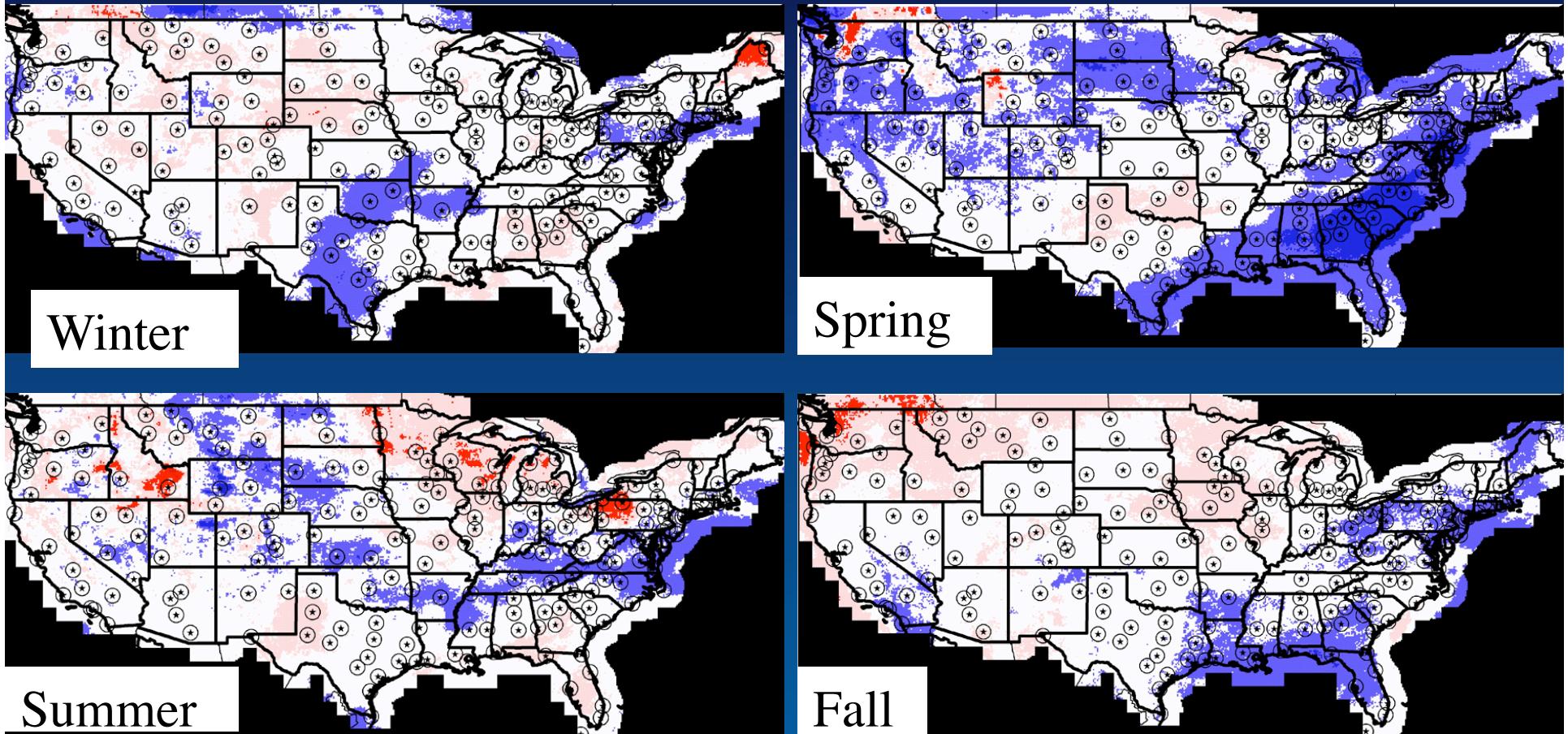
Use Year 2003 Results vs. 1998-2005



Pink = Annual 2003 > 1998-2005 mean by 0.2 or more

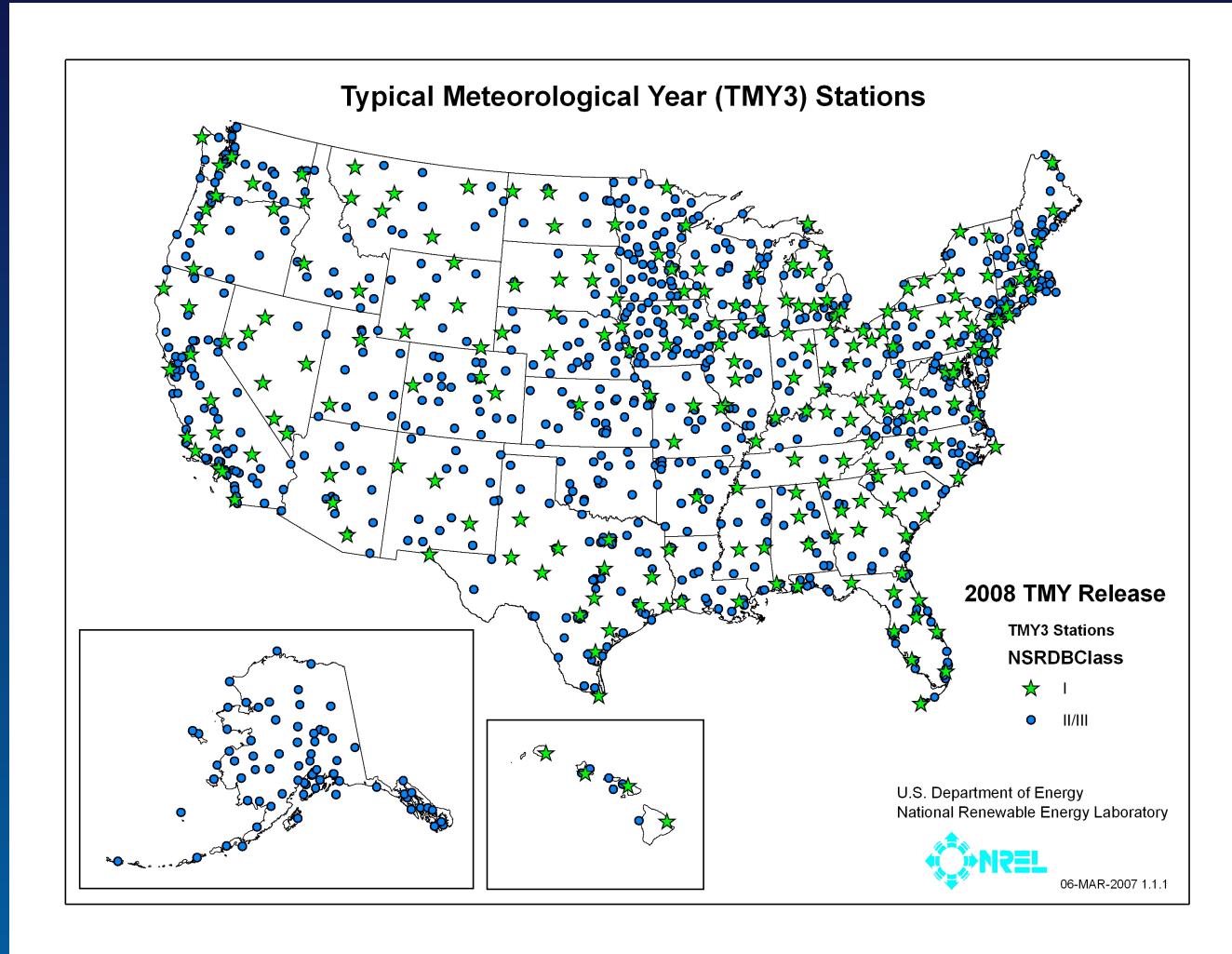
Blue = Annual 2003 < 1998-2005 mean by 0.2 or more

Seasonal Variations in Mean are Higher



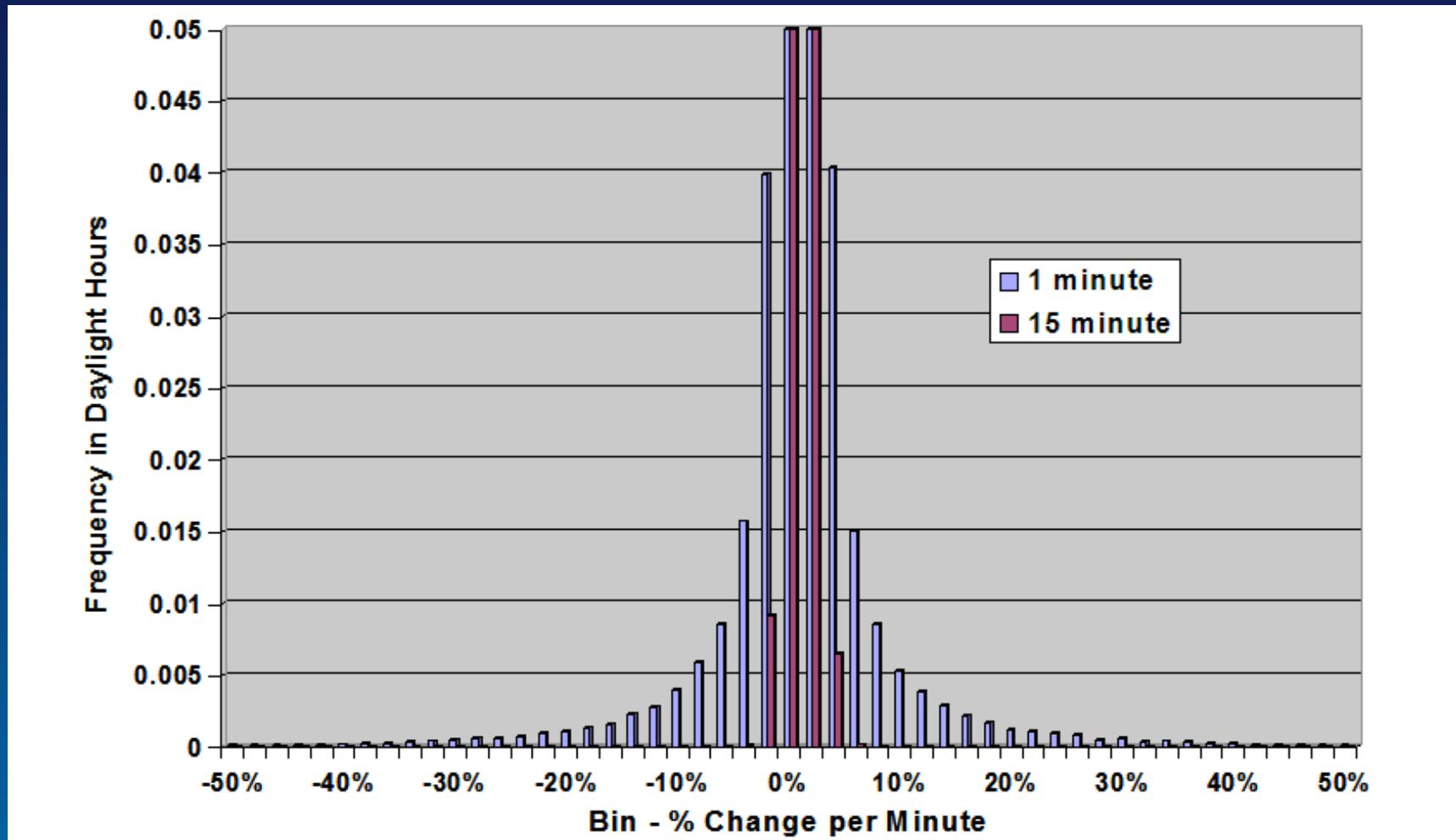
Red = Annual 2003 > 1998-2005 mean by 0.6 or more

Dark Blue = Annual 2003 < 1998-2005 mean by 0.6 or more

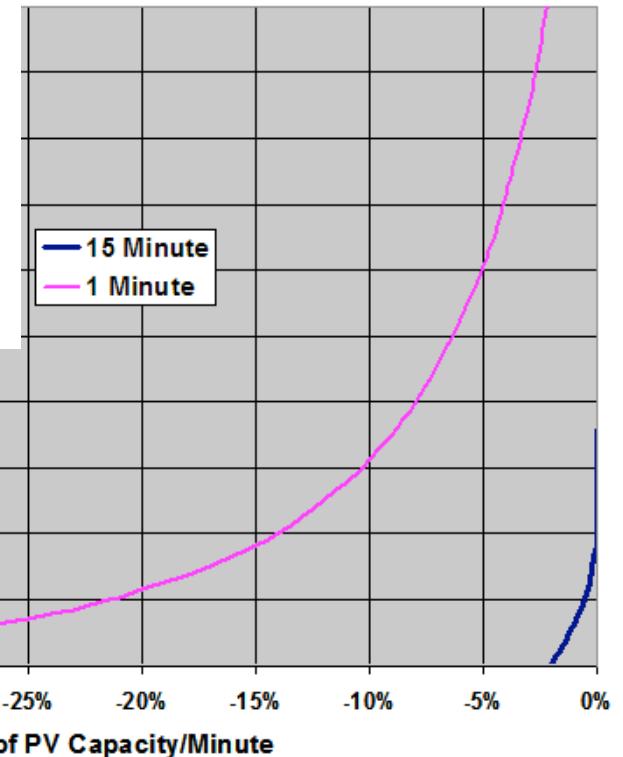
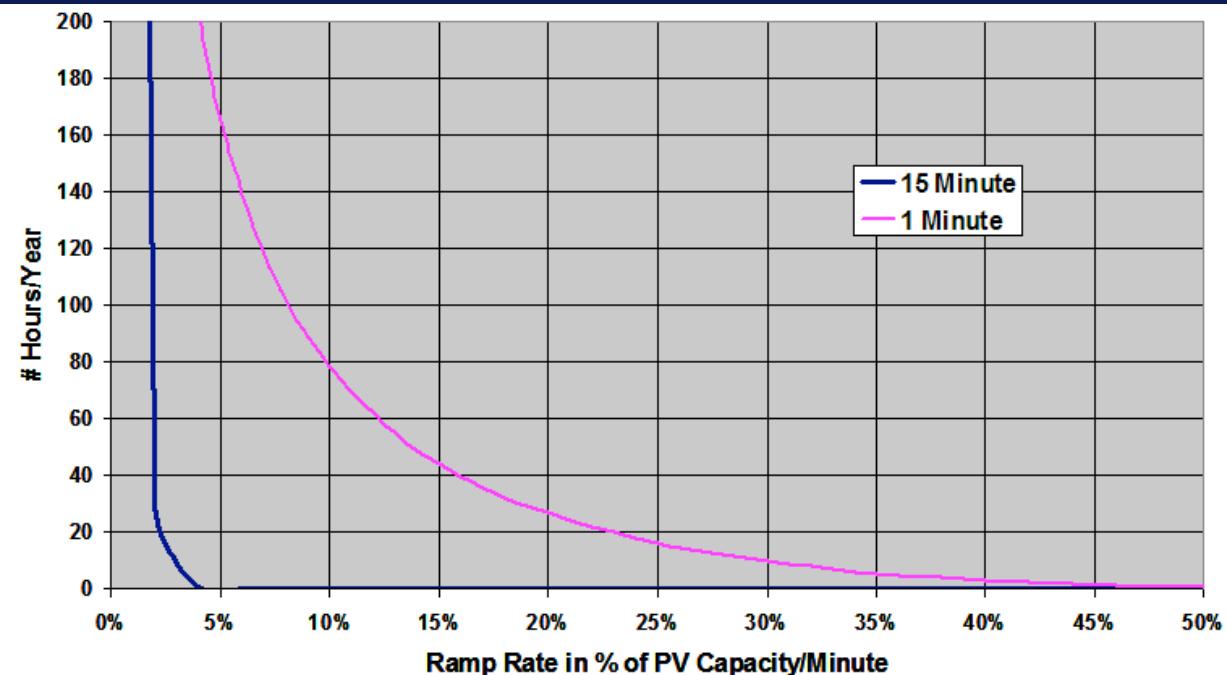


Final TMY3's (about 1000 stations) released April 2008.

PV Ramp Rates Using 1 Minute Solar Data



CFD “Tails” Show PV Ramp Rates



NREL/SRRL

Year 2003

1 Minute

15 Minute

Solar Monitoring Stations to Support CSP Deployments

Industry participants fund equipment and station operations

NREL funds design, deployment, and data processing/archiving

Numerous requests for participation



Tier 1 - Thermopile



Tier 2 - Rotating Shadowband

Summary and Conclusions

- Satellite-derived data sets are valuable in providing site-time specific solar resource data for analysis of grid-tied solar technologies
- Clear need for new data sets, analyses and capabilities to support large-scale grid-tied solar applications, with special needs for:
 - High temporal resolution data sets at site-specific locations
 - High spatial resolution data
 - Short term solar forecasts

Solar CSP Site Screening – Step 1

- DNI Resource > 6 KWH/M2/Day
- Ground Slope < 1% (Using 90 m. Terrain)
- Minimum Contiguous Area = 1 Square km
- Remove Federal Protected Lands
- Remove by Land Use – Water Bodies, Wetlands, Urban Areas.
- Remainder Gridded into 2 Square km CSP Cells – 203,000 Cells – 11.5 Million MW

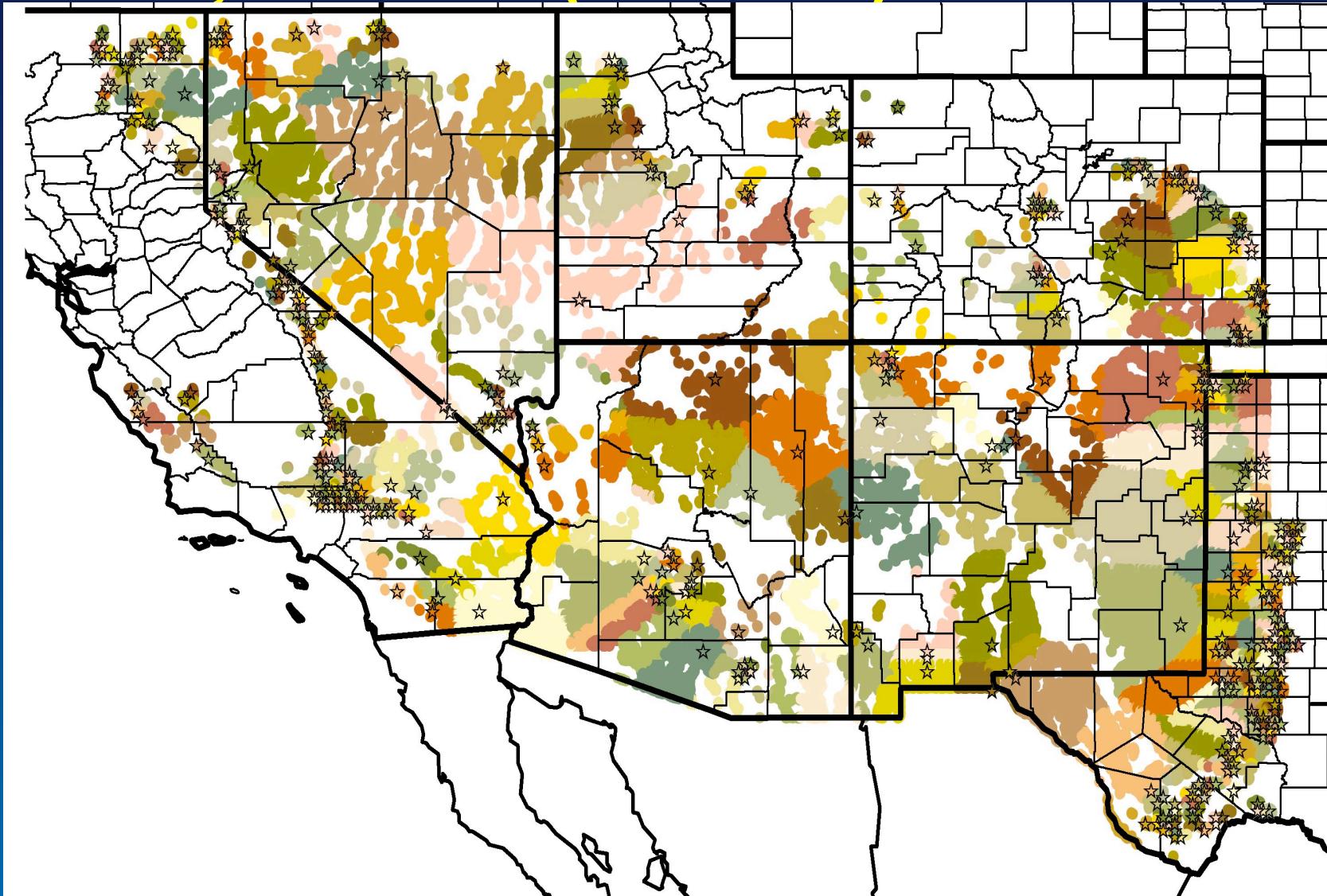
Solar CSP Site Screening – Step 2

- Start with 203,000 CSP cells, each 2 sq km
- Assign capacity factor for CSP plant, from location and average DNI
- Evaluate COE using capacity factor, proximity to transmission lines
- Assign to available transmission capacity using LCOE, until that capacity exhausted.
- 15,000 Assigned CSP cells = 267,000 MW

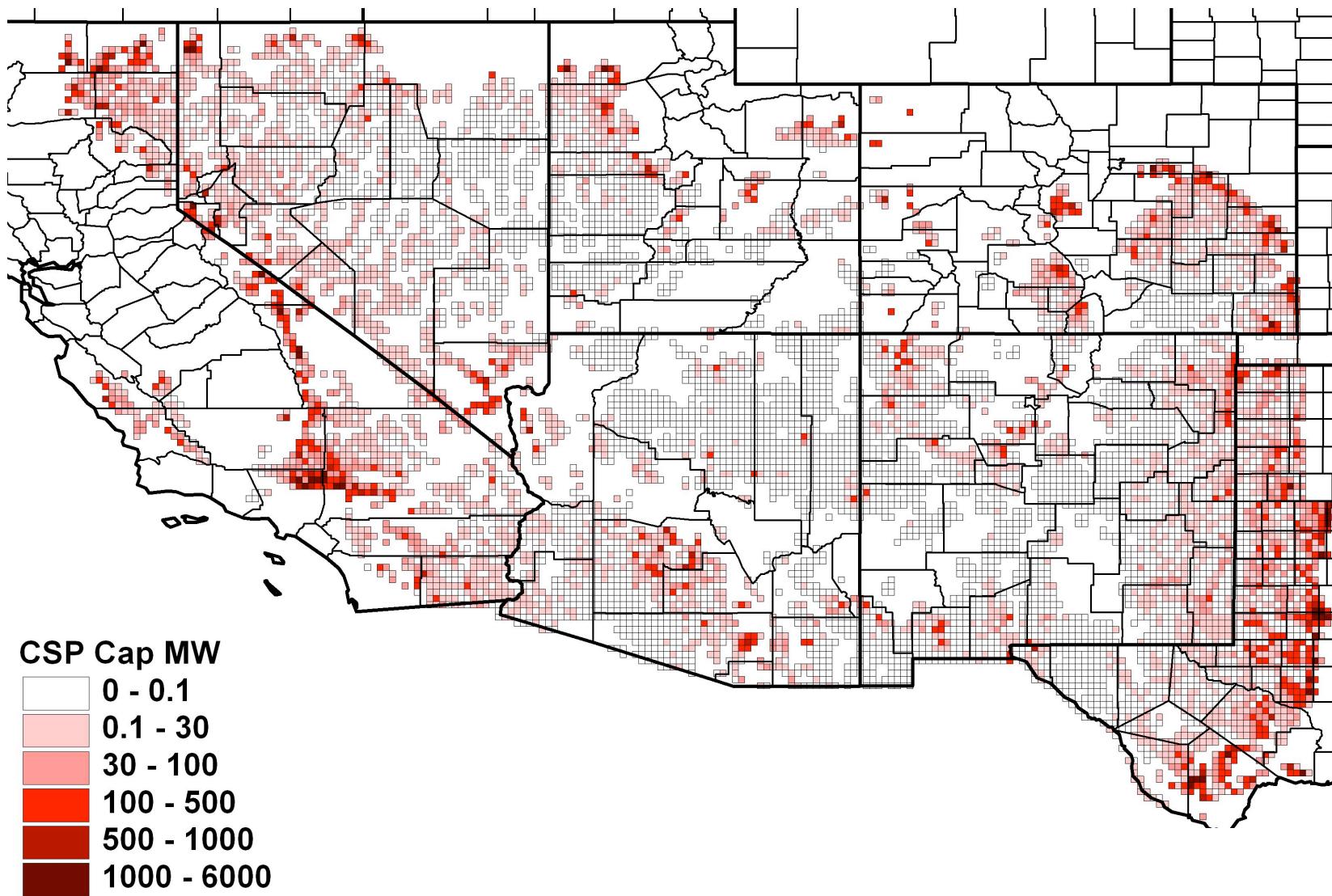
Solar CSP Site Screening – Step 3

- Relate each CSP cell (2 sq km) to the nearest SUNY cell (~100 sq km)
- 3900 SUNY Grid Cells contain some Assigned CSP capacity
- Subtotal and sort SUNY cells by assigned generation – max is about 5600 MW
- “Top 501” SUNY Grid Cells contain 207,000 Assigned MW – average 413 MW/Cell

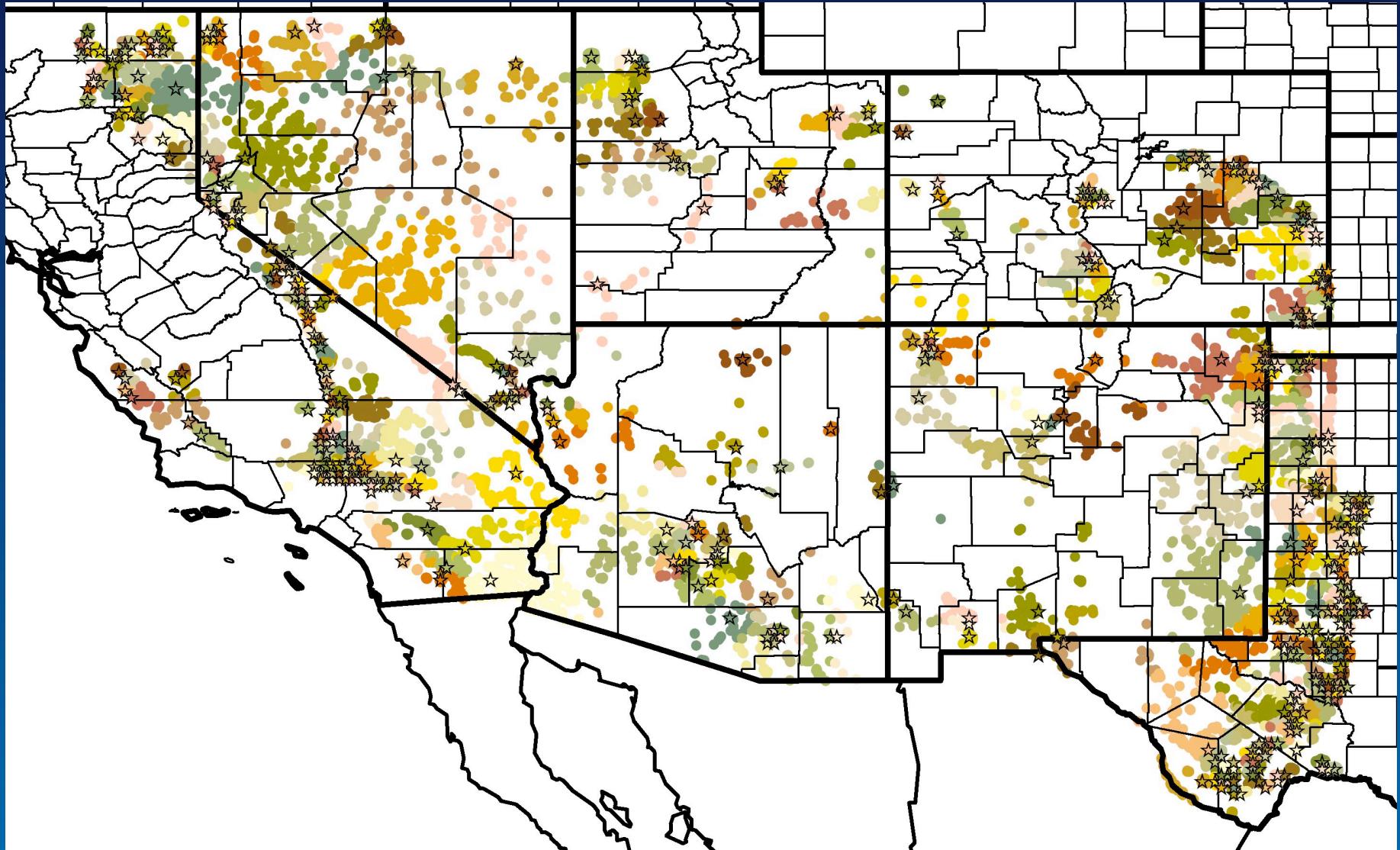
203,000 CSP (100 MW) Grid Cells



CSP Capacity per SUNY grid cell, WWSIS



15K Assigned CSP 100 MW Grid Cells





Innovation for Our Energy Future

MODELING CSP THROUGH HOURLY OUTPUT WITH THE SOLAR ADVISOR MODEL

Core Development Team: Nate Blair, Chris Cameron (Sandia), Craig Christensen, Paul Gilman (consultant), Steve Janzou (Consultant), Mark Mehos, University of Wisconsin - Madison

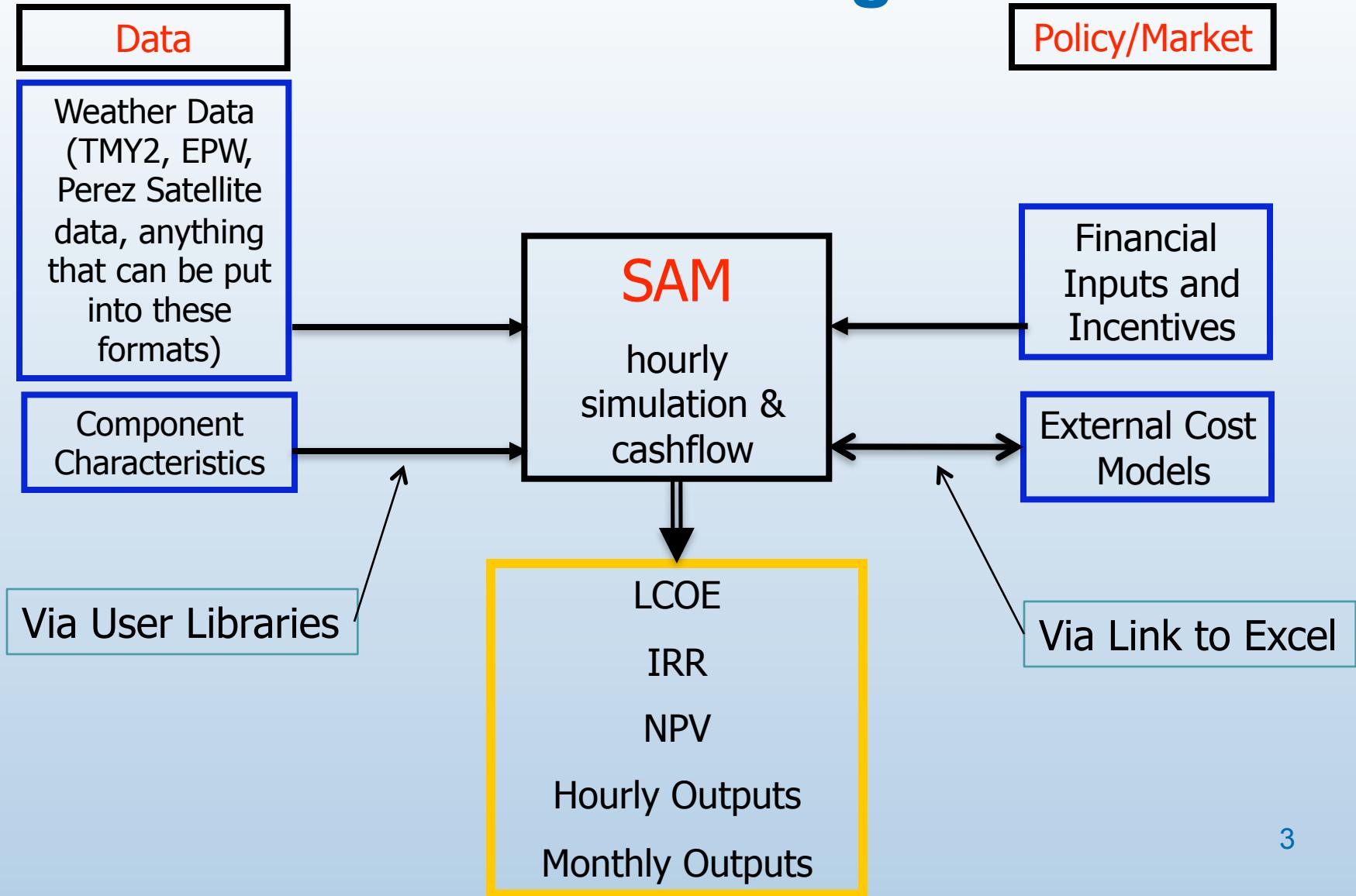
Free Download: <http://www.nrel.gov/analysis/sam>



SAM (Solar Advisor Model) Concept

- Original Vision (For DOE Multi-Year Planning by Lab analysts)
 - Combine all solar technologies in one modeling environment
 - concentrating solar power (CSP)
 - photovoltaics (PV)
 - solar heating (solar hot water, industrial process heat, etc.)
 - Model performance, costs and financing consistently across technologies for appropriate comparisons.
 - Calculate impact of R&D technology improvements on LCOE, NPV, etc. in various markets.
 - Extensive sensitivity analysis and output/ plotting capabilities
- Current Vision
 - Robust simulation tool that industry, the labs and DOE will use
 - Implementation of best performance models available
 - Policy, Markets and Technology Analysis
 - Siting Tool (especially with detailed Google-Maps solar satellite data)

SAM Block Diagram



Finance Model Options

- Detailed Cashflow model
- Output
 - LCOE, NPV, IRR, Revenue, Taxes, etc.
- Residential
 - Cash, Loan or Mortgage
- Commercial
 - Cash, Loan or 3rd Party Owner
- Utility Scale
 - IPP (at right) or IOU

Type of Financing: Utility - IPP

General

Analysis Period: 30 years
Inflation Rate: 2.50 %
Real Discount Rate: 8.00 %

Loan

Amount: \$237,687,354
Term: 20 years
Rate: 8.00 %/year
 Loan (Debt) Fraction: 50.00 %
 Optimize debt fraction to minimize LCOE.

Taxes and Insurance

Federal Tax: 28.00 %/year
State Tax: 7.00 %/year
Property Tax: 0.00 %/year
Sales Tax: 7.75 %
Insurance: 0.50 %

Federal Depreciation

No Depreciation
 MACRS Mid-Quarter Convention
 MACRS Half-Year Convention
 Straight Line: 7 years

Power Purchase Agreement (PPA)

PPA Escalation Rate: 1 %
 Optimize PPA escalation rate to minimize LCOE.

State Depreciation

No Depreciation
 MACRS Mid-Quarter Convention
 MACRS Half-Year Convention
 Straight Line: 7 years

Constraining Assumptions

Specify minimum equity Internal Rate of Return (IRR) and minimum Debt Service Coverage Ratio (DSCR) and Positive Cashflow requirement

Minimum Required IRR: 15.00 %
Minimum Required DSCR: 1.40
Positive Cashflow:

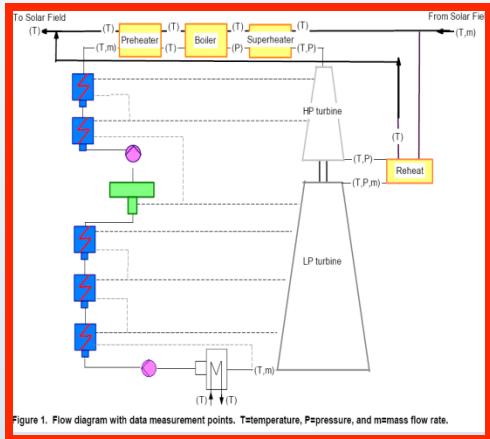
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Financial Incentives

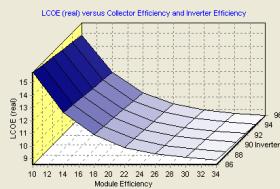
- Incentive Types
 - Tax Credits
 - Investment
 - Production
 - Investment Based Incentives (Buy-Downs)
 - Capacity Based Incentive
 - Production Based Incentive
- Separate possible entries
 - Federal
 - State
 - Utility
 - Other
- Modify Tax Implications

		Taxable Incentive		Incentive Reduces ITC Basis		Incentive Reduces Depreciation Basis	
		Federal	State	Federal	State	Federal	State
<input checked="" type="checkbox"/> Show Tax Details		<input type="button" value="Reset to Defaults for Market"/>					
- Investment Tax Credit (ITC)							
Amount (\$)				n/a	no	n/a	n/a
<input type="checkbox"/> Federal		0				<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
<input type="checkbox"/> State		0		no	n/a	n/a	n/a
% <input checked="" type="checkbox"/> Federal		10		1E99		<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
<input type="checkbox"/> State		0		1E99	no	n/a	n/a
+ Production Tax Credit (PTC)							
- Investment Based Incentive (IBI)							
Amount (\$)				<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<input type="checkbox"/> Federal		0				<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
<input type="checkbox"/> State		0		<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<input type="checkbox"/> Utility		0		<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<input type="checkbox"/> Other		0		<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
% <input type="checkbox"/> Federal		0		1E99	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
<input type="checkbox"/> State		0		1E99	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
<input type="checkbox"/> Utility		0		1E99	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
<input type="checkbox"/> Other		0		1E99	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
+ Capacity Based Incentive (CBI)							
+ Production Based Incentive (PBI)							

SAM Support of Research for Underlying Models



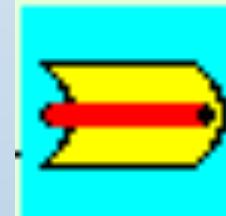
Performance Map / Physical Model



SAM

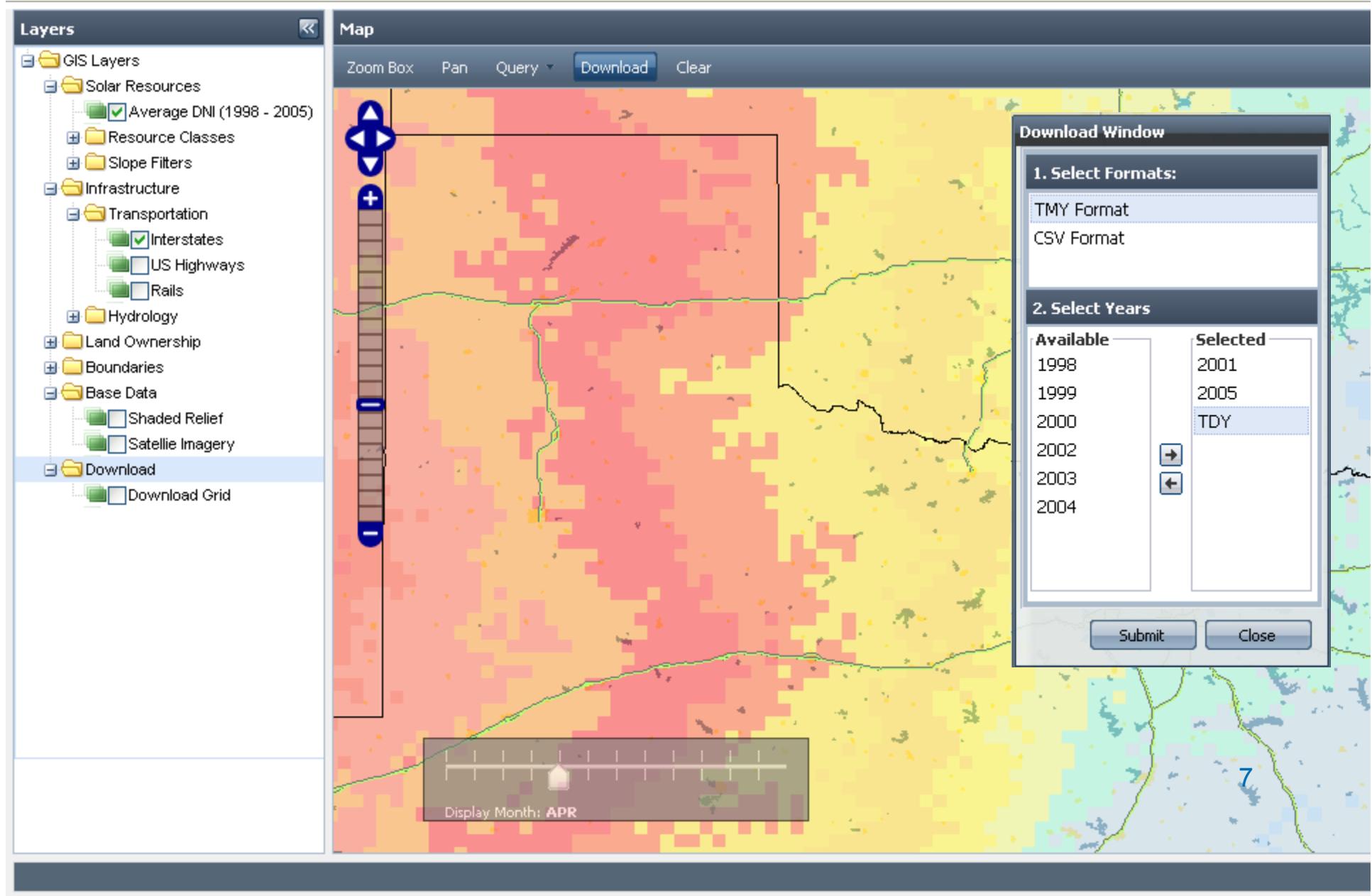


TRNSYS



- Performance Models
- Advanced CSP Trough
 - Dish/Stirling
 - Power Tower
 - Enhanced PV Model
 - Sandia Inverter
 - CPV
 - Other???

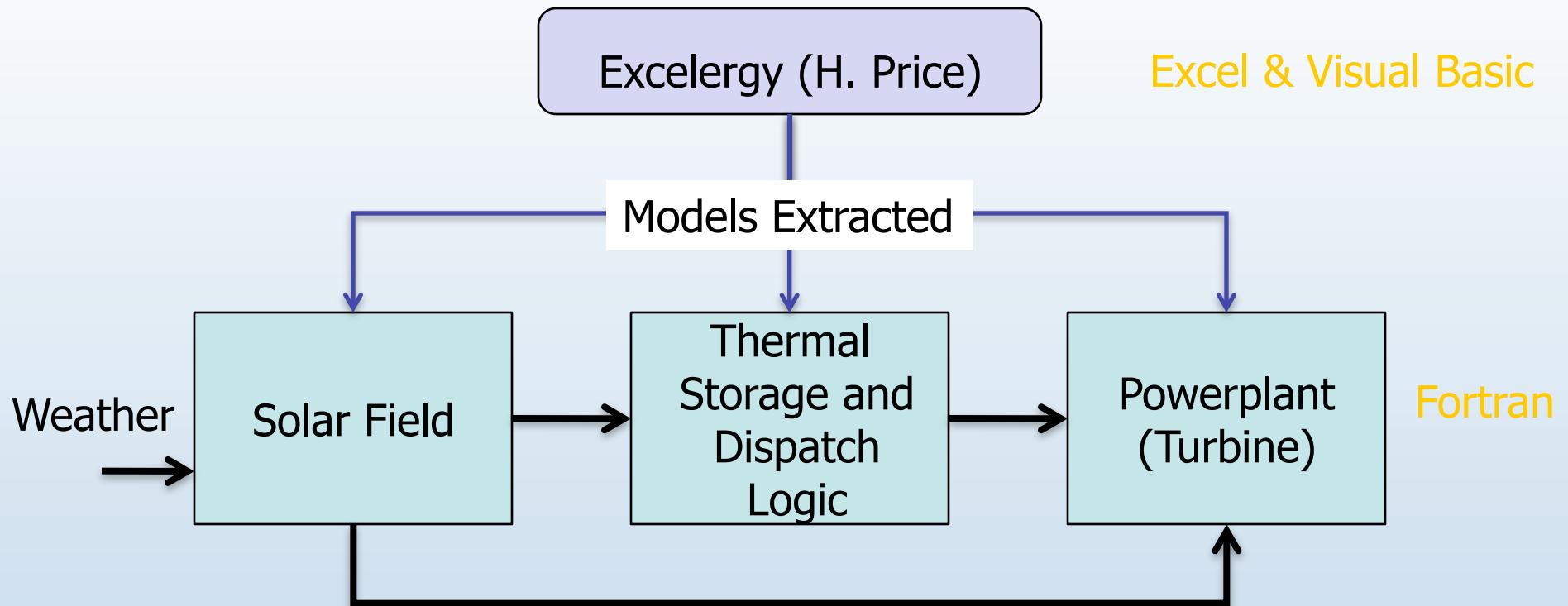
Download and use of recent solar satellite data



SAM Solar Performance Models

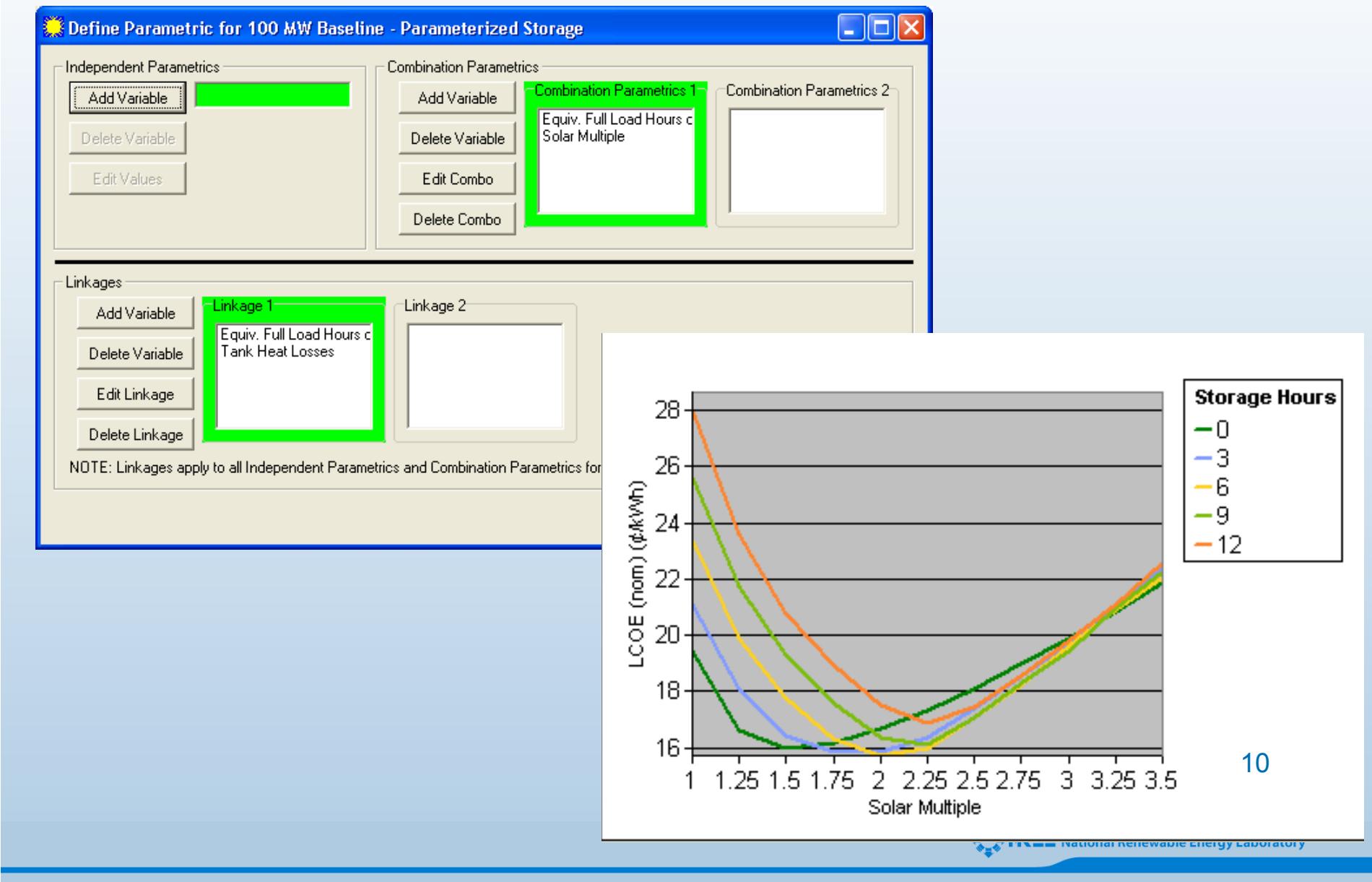
- PV Modules
 - Single-point efficiency with temp. coefficient
 - Single-pt eff. for concentrating PV
 - Sandia PV Array Performance Model
 - CEC/Wisc 5-parameter model
- Inverters
 - Single-point efficiency inverter model
 - Sandia Inverter Performance Model
- **CSP**
 - Parabolic Trough (based on NREL's Excelergy model)
- Generic
 - Very simple capacity * capacity factor model for comparison with non-solar technologies

Parabolic Trough Model Components



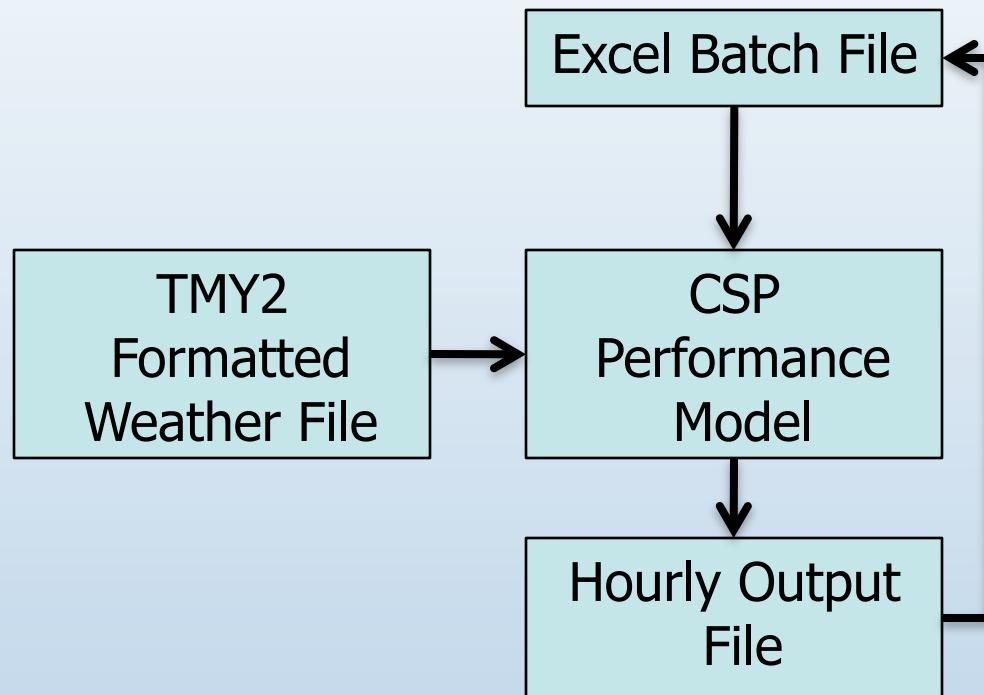
- Calculates sun position
 - Optical Efficiency
 - Curve-fit for receiver heat losses
 - Misc. solar field losses
- Tracks energy in/out of storage
 - 2-Tank or Thermocline
 - Dispatch storage to time-of-use periods/rules
 - Storage losses
- Part-load curve fit
 - Temp. Correction
 - Allows for fossil backup
 - Parasitic plant loads

SAM Strength – Parametric Analyses



Excel Batch File for WWSIS

Process for Generating CSP Hourly Output files



Hourly File Contents and Format

TIME = Hour of the year

DOY = Day of the Year

MONTH = Month of the Year

HOM = Hour of the Month

DOM = Day of the Month

HOD = Hour of the Day

TOUPeriod = Time of Dispatch for Storage

Qabs = Absorbed energy in field (W/m²)

QsfAbs = absorbed energy for solar field (MW)

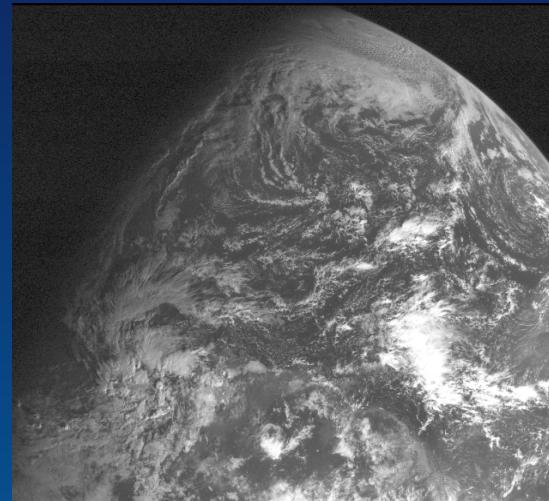
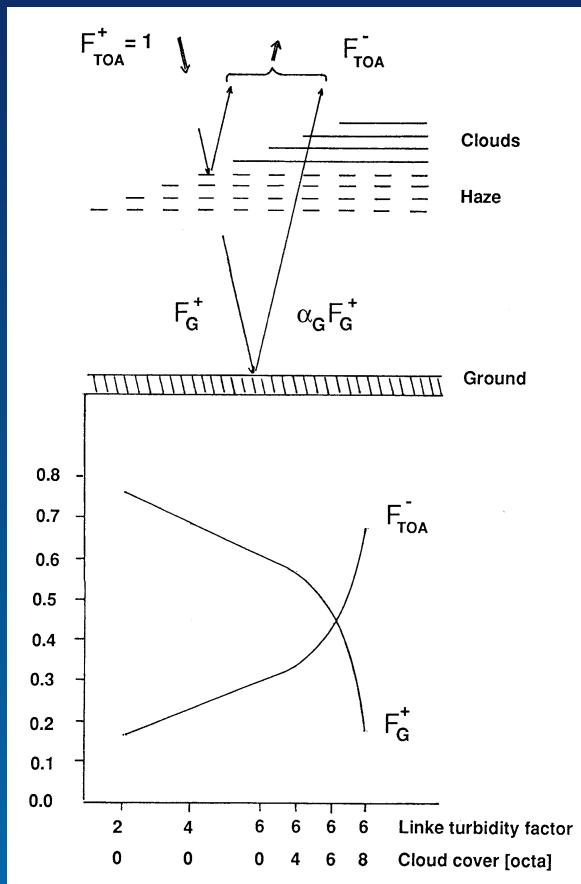
Qsf(MW) = Output Power (MW)

E_net = Net electric energy production (MW)

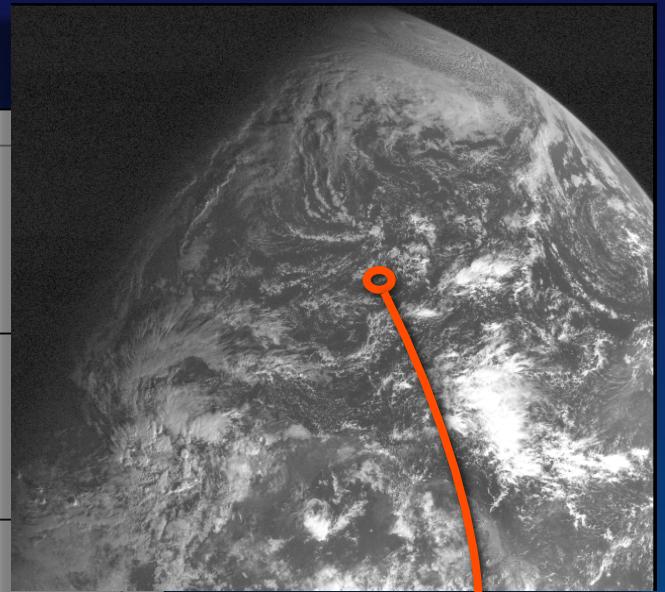
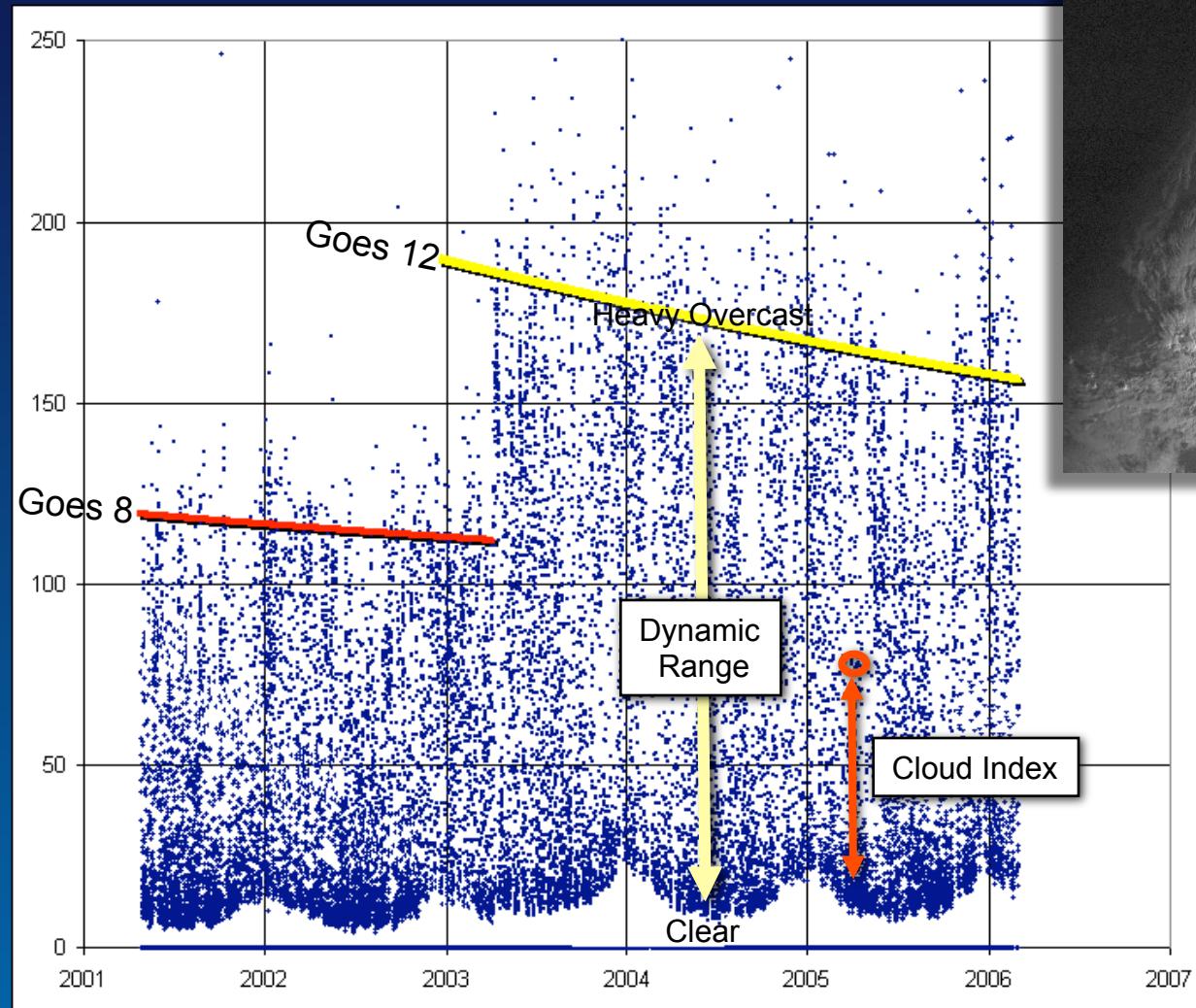
Hourly File Contents and Format

ADDITIONAL SLIDES

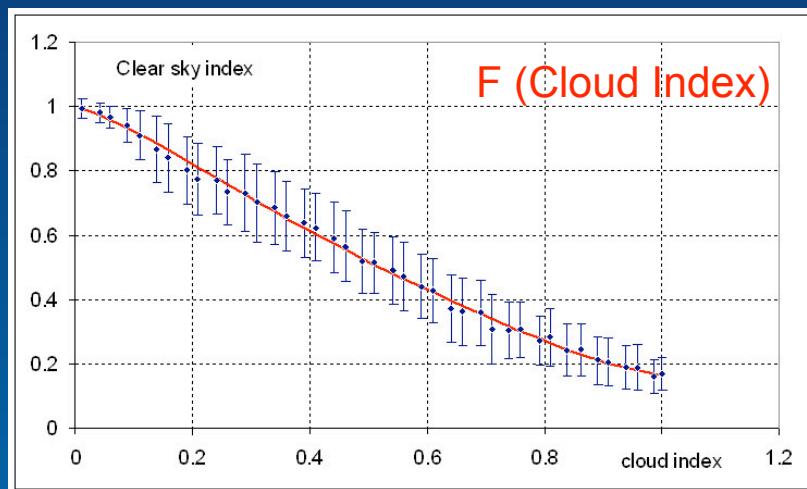
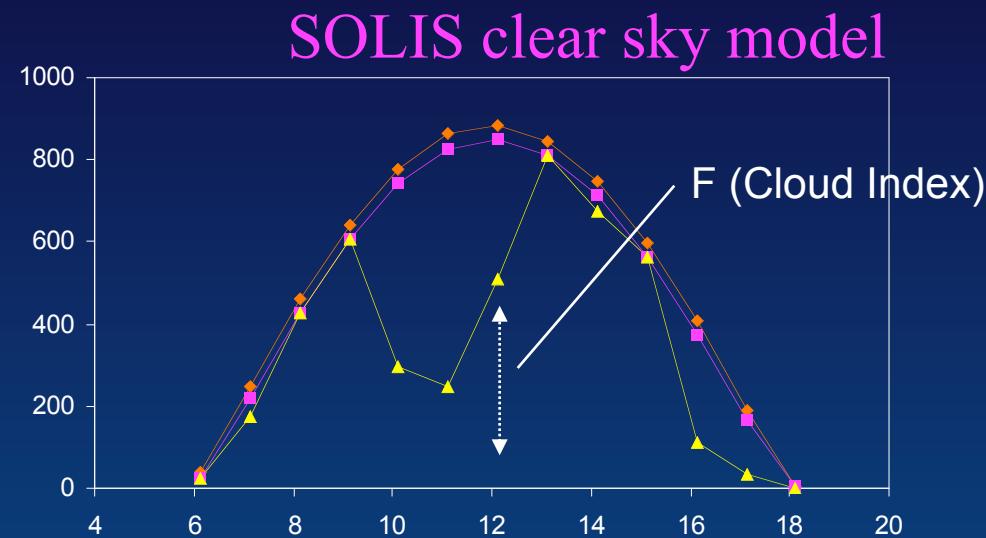
Basic Principle



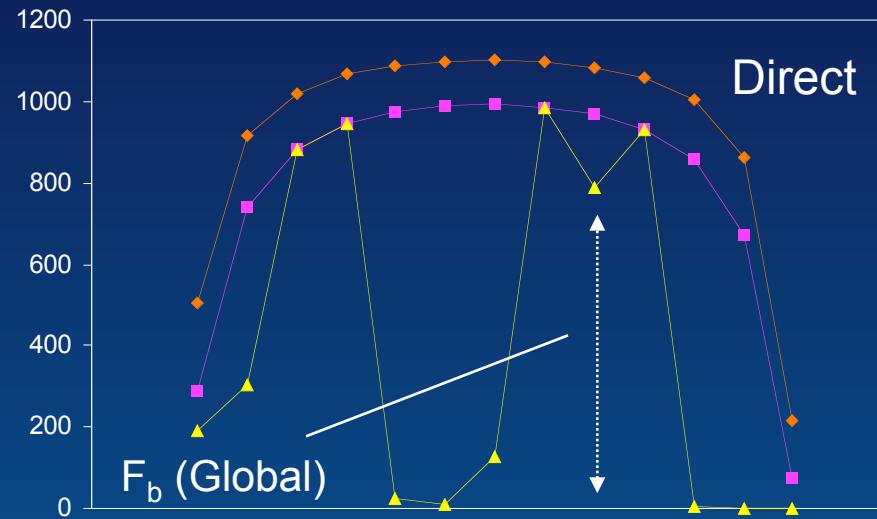
$$T = \frac{F^+_{G}}{F^+_{TOA}} = a - b \frac{F^-_{TOA}}{F^+_{TOA}}$$



GLOBAL IRRADIANCE



BIRD MODEL



$$F_b = \frac{\text{Dirint (Global)}}{\text{Dirint (Global}_{\text{clear}}\text{)}}$$